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EFFECT OF DISCRETE STEEL FIBERS ON THE BEHAVIOUR OF R. C. BEAMS EXPOSED TO FIRE

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ABSTRACT

The main objective of this paper is study the influence of steel fibers on the behavior of R.C beams exposed to fire under loading on the behaviour of reinforced concrete (RC) beams under different fire and cooling conditions. Eighteen beams were tested with rectangular section its dimensions (120 * 250 * 1650) mm, divided into six groups, using different different volume of fraction (Vf) equal to (0.0%, 0.50%, and 0.75%); also use different compressive strength (35MPa, 65MPa). Groups one and two were tested at room temperature. The third and fourth groups were loaded by 35% of the load measured at room temperature and then subjected to a temperature of 500 °C for half hour then the load was increased up to failure. The fifth and sixth groups were loaded by 35% of the load measured at room temperature and then subjected to a temperature of 500 °C for half hour then cooling by water then the load was increased up to failure. Analysis of test results shows that adding discrete steel fibres to high strength concrete (HSC) increased the residual stiffness of the tested specimens after firing and decreased the rate of the deflection gain during firing. And also, the ductility of RC tested beam exposed to fire improved. Finally, the recommend optimum ratio of discrete steel fibres depends on the compressive strength, where for NSC the optimum ratio could be 0.50% of the total concrete weight, and for HSC the optimum ratio could be more than 0.75% of the total concrete weight.

KEYWORDS: Discrete Steel Fibers, Fire Condition, RC Beam, Ductility & Deformability

INTROUDUCTION

Fire remains one of the serious potential risks to most buildings and structures. The extensive use of concrete as a structural material has led to the need to fully understand the effects of fire on concrete. Generally concrete is thought to have good fire resistance [1]. Exposing concrete to high temperature causes strength deterioration, reduction in bond strength with reinforcement and increase in the risk of reinforcement corrosion due to high permeability and cracks [2]. Previous studies indicate that the concrete the reduction of strength happened in concrete at high temperatures [3-8]. This reduction depends on many factors such as: specimen dimensions, loading conditions, concrete strength, temperature level, heating duration and method of cooling [9-12]. Also previous studies indicate that concrete containing steel fiber had high tensile strength than that of plain concrete and using of fibers may lead to reduction in the amount of cracking under serviceability conditions [13-17]. Up till now, there are many studies about the mechanical properties of reinforcement concrete (RC) beam subjected to high temperature. Almost the investigations have been focused on the mechanical behaviors of RC beams during heating or after heated under an unloading state [18-22], only have a few studies been reported on the mechanical properties of RC beams after exposed to fire in a loading sate [24]. So that the aim of this research is to study the effect of adding discrete steel fibres on the behavior of R.C beams exposed to fire under loading.

EXPERIMENTAL PROGRAM

Eighteen R.C. beams with rectangular cross-section, sized 120 mm (width) x 250 mm (height) x 1650 mm length (Figure 1), were manufactured. Concrete mix used to cast the tested RC beams with concrete compressive strength equal to 35MPa consisted of Portland cement, natural aggregates and natural water. Silica fume and super plasticizer were added to the concrete mix used to produce concrete with compressive strength 60MPa. Corrugated Steel fiber of 0.5mm thickness, 3mm width and 50mm length with aspect ratio equal to 100 were used with fiber content percentages equal to 0.0, 0.5% and 0.75%.

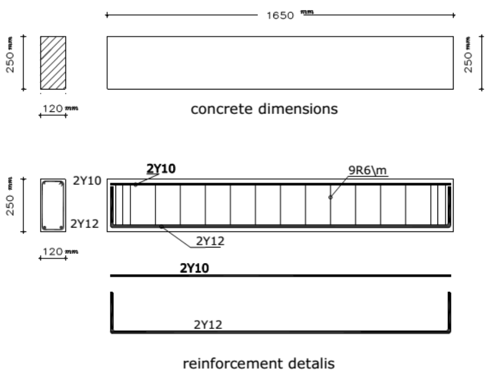


Figure 1: Details of Typical Specimen

Mixing was performed using a concrete tilted rotating drum mixer with maximum capacity 0.125 m^3. Sand, dolomite, cement and silica fume were dry mixed while the discrete fibers were gradually added to the mix until a homogenous color was observed. Then, the water with the super plasticizer was gradually added, while mixing for additional two minutes, after which the concrete became homogeneous. The concrete was cast in the molds and cured by covering the specimens with moist burlap sheets until testing.

Three parameters were considered in this study; variable discrete steel fibers content, concrete compressive strength and different fire and cooling conditions. Details of tested beams with different parameters are shown in Table 1.

Table 1: The Experimental Program & Results

Group	Specimen	Compressive Strength (MPa)	Fiber Content (%)	Firing Temperature (° C)	P_u (kN)	Pu/Pu(No Fire, No Fiber)	Pu/Pu(Control Group)	Failure Type	Fire Condition
G1	B1-35-0.0-C	35	0	non	87	1.00	100	Shear& Flexural	No Fire
	B2-35-0.50-C	35	0.5	non	95	1.00	109	Shear& Flexural	
	B3-35-0.75-C	35	0.75	non	101	1.00	1.16	Shear& Flexural	
G2	B4-65-0.00-C	65	0	non	95	1.00	1.00	Shear& Flexural	
	B5-65-0.50-C	65	0.5	non	100	1.00	1.05	Flexural	
	B6-65-0.75-C	65	0.75	non	109	1.00	1.15	Flexural	
G3	B7-35-0.00-H	35	0	500	85	0.98	1.00	Flexural	Fire & Air Cooling
	B8-35-0.50-H	35	0.5	500	92	0.97	1.08	Flexural	
	B9-35-0.75-H	35	0.75	500	97	0.96	1.14	Flexural	
G4	B10-65-0.00-H	65	0	500	89	0.94	1.00	Flexural &bond	
	B11-65-0.50-H	65	0.5	500	95	0.95	1.07	Flexural	
	B12-65-0.75-H	65	0.75	500	104	0.95	1.17	Flexural	
G5	B13-35-0.00-W	35	0	500	83	0.95	1.00	Shear& Flexural	Fire & Water Jet Cooling
	B14-35-0.50-W	35	0.5	500	88	0.93	1.06	Flexural	
	B15-35-0.75-W	35	0.75	500	93	0.92	1.12	Flexural	
G6	B16-65-0.00-W	65	0	500	91	0.96	1.00	Flexural	
	B17-65-0.50-W	65	0.5	500	98	0.98	1.08	Flexural	
	B18-65-0.75-W	65	0.75	500	107	0.98	1.18	Flexural	
B18-60-0.75-W = B number of beam-compressive strength-the fiber content percentage- the cooling condition									

The eighteen beams were divided into six groups; each of these groups has three beams containing steel fiber with volume of fraction (Vf) equal to equal to 0.0, 0.5%, and 0.75% of the concrete volume, respectively. Groups one, three and five were prepared from normal strength concrete with compressive strength equal to 35MPa while groups two, four and six were prepared from high strength concrete with compressive strength equal to 65 MPa. The first and second group, G1 and G2, were not exposed to fire and are used as control. Groups three and four, G3 and G4, were initially loaded up to 0.30 of the ultimate load resulting from the control beams of groups G1, and G2. Under this load, the beams were exposed to fire until the temperature reached 500^{o} C within half an hour. After that, the fire was stopped and the beams were left to cool in air while the load was increased up to the failure. Groups G5 and G6 were also initially loaded up to 0.30 of the ultimate load resulting from the control beams of groups G1 and G2. Under this load, the beams were exposed to fire until the temperature reached 500^{o} C within half an hour. After that, the beams were cooled with water jet then the load was increased up to failure.

Figure 2: Experimental Setup

EXPERIMENTAL SETUP AND TESTING

A special setup for testing the beams was constructed as shown in Figure 2. It consisted of a steel frame formed of I-beams resting on four steel columns to support the beams during firing and loading. The span of the tested beams between supports is 1.5m. Loading was undertaken using an additional I-beam acting as a lever. One end of the beam was attached to the strong floor of the laboratory using threaded steel rods which provided a hinge support for the lever. The other end of the lever beam was provided with a hanger for supporting concrete weights. The lever beam applied its reaction load in the center of the tested beam. A load cell was provided between the lever beam and the tested beam to accurately measure the applied load. Additional threaded rods were attached to the strong floor near the hung weights. By tightening nuts to these rods, the lever beam was forced to increase the load on the tested beam in a displacement control manner.

Loading was initially achieved by increasing the number of concrete weights hung from the end of the lever beam until the reaction load acting in the center of tested beam reached 30% of ultimate load of the control beams. After applying 30% of the failure load of the control beam, displacement was used to control loading at each load stage. This ensured that the load remained constant for measuring and observing. This arrangement avoided the use of hydraulic jacks during fire.

Digital load cell of capacity of 550 kN and accuracy of 0.1 kN was used to measure the applied loads. The values of the applied loads were recorded from the monitor connected to the load cell. The beams were tested using an incremental loading procedure. The vertical displacement of the tested beams was recorded using two electrical dial gauges, one at the middle of beam and the other at a distance equal to one-fourth the span measured from the support. The load cell and the two dial gauges were protected from fire by wrapping them with Rockwool mats.

TEST RESULTS AND ANALYSIS

The experimental results revealed the following behavior for RC beam containing discrete steel fiber when exposed to different fire and cooling conditions. The considered elements of the behavior are cracking patterns, modes of failure, load deflection curves, ultimate loads and maximum deflections.

Crack Patterns and Modes of Failure

The crack patterns and modes of failures of the tested beams are shown in figure 4. For groups G1 and G2, figures 3-a and 3-b show that all beams failed in diagonal shear-flexure. By adding the fibers, the crack widths decreased, the numbers of cracks decreased and the shear cracks became less pronounced. In group two, The addition of fibers reduce the cracks near to the support and the mode of failure can be flexure failure, this may be due to high strength concrete prevented the occurrence of the shear cracks.

Figures 3-c and 3-d show the crack patterns and modes of failures of groups G3 and G4 which were exposed to fire and were failed while cooling in air. The firing changed the modes of shear-flexural failure groups G1, and G2 to flexural–bond failures of group G3 and G4 except beam B7 shear-flexure failure happen. This is a result of a reduction of the concrete tensile strength relative to the shear strength. The beneficial effect of the fibres in reducing the size of the cracks of groups G3 and G4 was similar to groups G1 and G2, but the number of cracks in groups G3, and G4 increased than that control groups (G1, G2)

Figures 3-e and 3-f show the crack patterns and modes of failures of groups G5 and G6 which were exposed to fire then cooled with water before increasing loading. The firing changed the modes of failure of groups G5 and G6 to flexural failures. Cracking for both groups was more concentrated in the middle zone of the beams and the diagonal cracks disappeared compared to control groups (G1 and G2).

Figure 3a: The Crack Patterns for Group (G1)

Figure 3b: The Crack Patterns for Group (G2)

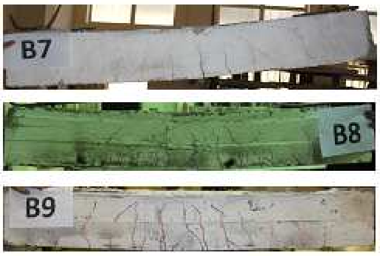


Figure 3c: The Crack Patterns for Group (G3)

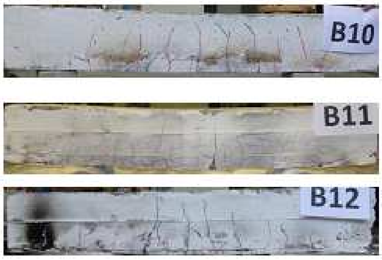


Figure 3d: The Crack Patterns for Group (G4)

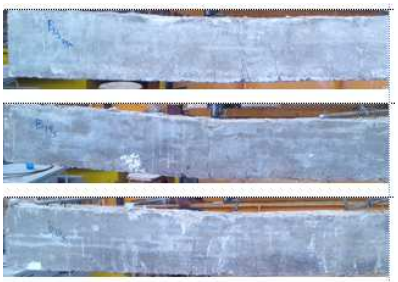


Figure 3e: The Crack Patterns for Group (G5)

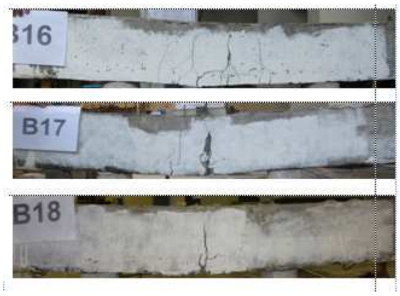


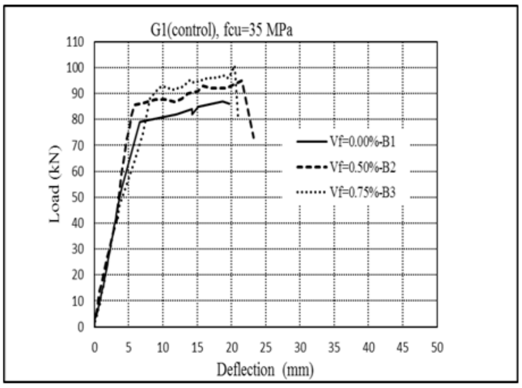
Figure 3f: The Crack Patterns for Group (G6)

Figure 3: The Crack Patterns of Tested Specimens

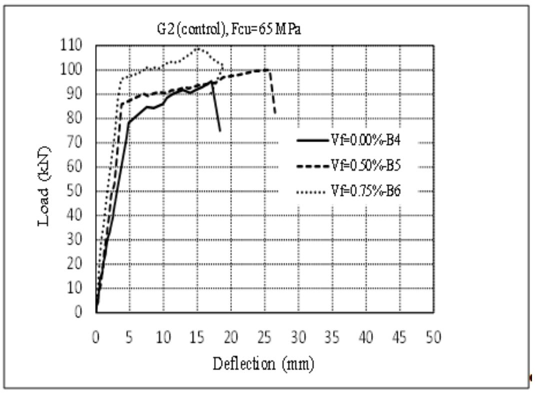
Load Deflection Curves

The load deflection curves of the tested beams are shown in figure 4. For groups G1 and G2, figures 4-a and 4-b show that adding discrete fibers increased the stiffness of the tested beams. For HSC, by the increase in fibers content percentages the stiffness and resilience of RC beam increased. But for NSC, the increase in stiffness of RC tested beam with fiber content ratio equal to 0.5% is highest. Adding the fibers resulted in general increase in the ultimate strength of the beams and the ductility.

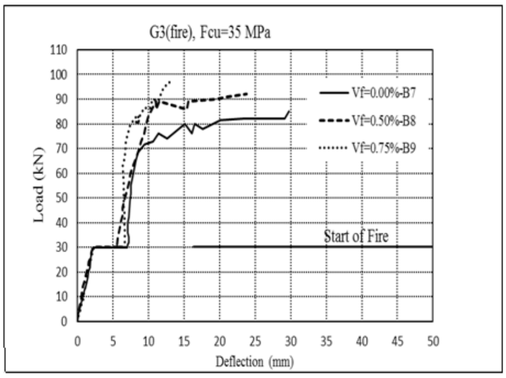
Figures 4-c and 4-d show the load deflection curves of groups G3 and G4 which were exposed to fire and were failed while cooling in air. For HSC and NSC, by the increase in fibers content percentages the stiffness of tested RC beam increased. The curves show a plateau at about one third of the failure load due to the deflection increase resulting from expansion of the lower part of the beam due to fire. The resulting temperature induced deflection is more for NSC when compared to that of HSC. This is a direct result of the higher modulus of elasticity of HSC. The slope of the load deflection curves after firing and before yielding for NSC decreased and the slop of load deflection curves can be three portions instead to two because of the correlation thermal expanded of fibre reinforced concrete (FRC) is more than that of RC. The temperatures increase in main steel reinforcement for FRC earlier than RC without fibers. The ductility of the NSC, and HSC after yielding is improved expected B9.



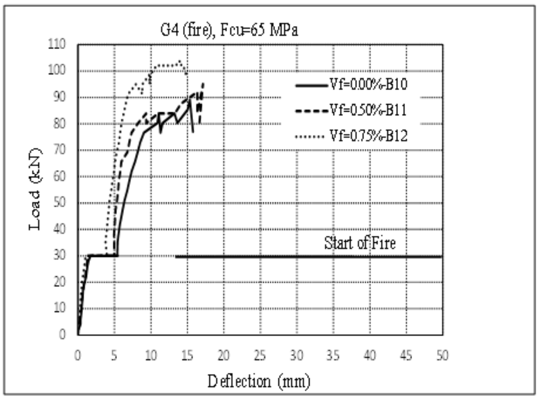
a) fcu=35MPa - No Fire



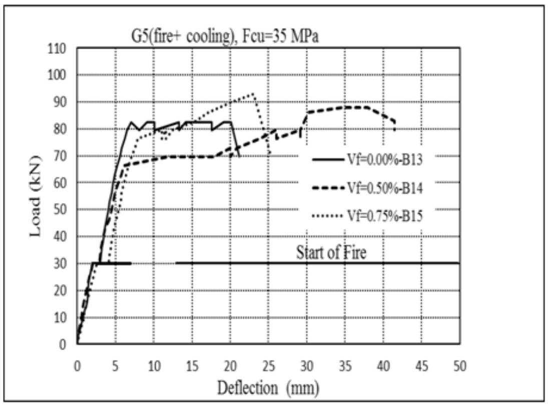
b) fcu=65MPa - No Fire



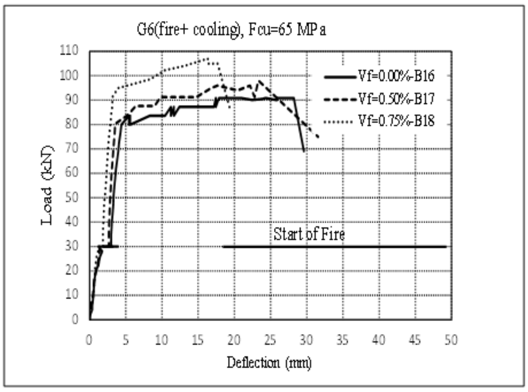
c) fcu=35MPa - Exposed to Fire



d) fcu=65MPa - Exposed to Fire



e) fcu=35MPa - Exposed to Fire then Cooled



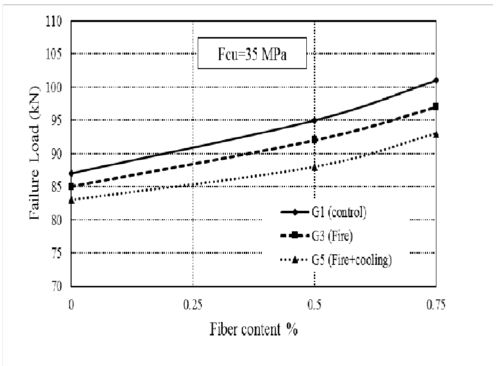
f) fcu=65MPa - Exposed to Fire then Cooled

Figure 4: Effect of Fibre Content on Load Deflection Curve

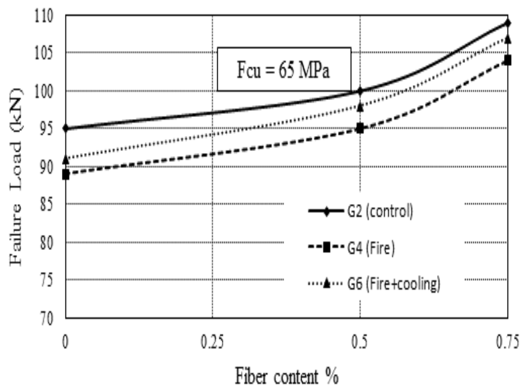
Figures 4-e and 4-f show the load deflection curves of groups G5 and G6 which were exposed to fire then cooled by water before increasing the load to fail the specimens. For NSC, by the increase in fibers content percentages, the ductility increased. But for NSC, by the increase in fibers content percentages the stiffness and resilience of RC tested beam increased, and the ductility increased by adding fiber content 0.5% and decreasing by adding 0.75%. Form this concluded that for RC tested specimens exposed to fire then cooling the optimum ratio for ductility is 0.5% and for ultimate load is 0.75%.

Failure Load

The failure loads of the tested specimens are given in figure 5-a and table 1. In the control group (G1) with normal strength of concrete (NSC), the ultimate load increased by 9.0% and 16% by using discrete fiber content ratio equal to 0.5%, and 0.75% respectively. Under fire (G3), the ultimate load increased 8% and 14% by using discrete fiber content ratio equal to 0.5%, and 0.75% respectively. Finally under fire and cooling (G5), the ultimate load increased 6% and 12% by using discrete fiber content ratio equal to 0.5%, and 0.75% respectively.



a) fcu=35MPa



b) fcu=65MPa

Figure 5: Effect of Fiber Content for the Different Fire Conditions on Retained Failure Load

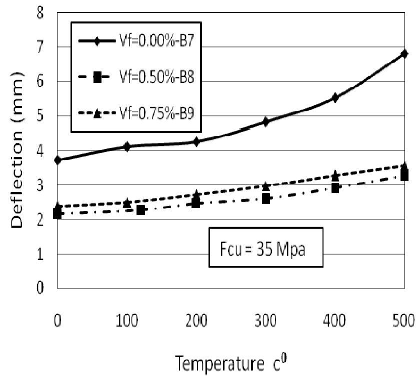
As shown in figure 5-b and table 1, for high strength concrete, group G2, the ultimate load increased by 5.0% and 15% by using discrete fiber content percentage equal to 0.5%, and 0.75% respectively. Under fire, G4, the ultimate load increased 7% and 17% by using discrete fiber content ratio equal to 0.5%, and 0.75% respectively. Finally under fire and cooling, G6, the ultimate load increased 8% and 18% by using discrete fiber content ratio equal to 0.5%, and 0.75% respectively. It can be concluded that, adding discrete steel fibers with 0.75% are more efficient in increasing the strength of beams for HSC than NSC. And the optimum ratio for discrete steel fiber content is equal to or more than 0.75%.

The relative strength of the NSC which was fired and failed before cooling varied between 96% and 98%. Which indicate that the strength reduction is marginal. When the specimens are failed after cooling, the retained strength ranges between 95 and 92% compared to the unfired specimens. This means that the reduction in strength increases after cooling, this may due to the effect of fracture process under the effect of the water on the cracked and high permeability of concrete matrix.

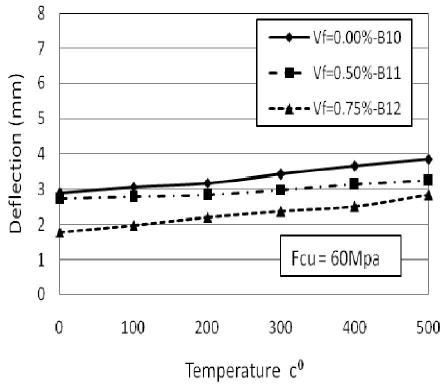
For the tested beam specimens of HSC, the retained strength after firing and before cooling varies between 95 and 94%. This means that the reduction in high strength concrete specimens is more than in normal strength concrete specimens. After cooling the strength is reduced further and the retained strength varies between 98 and 96%. This means that the reduction in strength decreases after cooling by water, The reason may be due to the cement past is strong as gravel and the Cracks usually appeared in the final stage of loading. In all cases, the retained strength decreases with the fibre content. It has to be added that in all cases, the strength of concrete containing fibres remained higher than the specimens without fibres.

Temperature Induced Deflection

Figure 6 shows the increase in deflection due to temperature increase. Adding discrete steel fibres has a higher effect on the normal strength concrete as compared to the high strength concrete. For NSC and HSC, increasing doses of fibres reduces the deflections. The rate of deflection increase with temperature is very similar for all tested specimens with high strength concrete. But, the rate of deflection decreased by adding fibres during fire. The reduction in the considered rate of deformation may be explained by increasing the modulus of elasticity and the moment of inertia because of mixing steel fiber while the reduced value of the deflection may be a result of significant increase in the tensile strength of the material.



a) fcu =35MPa



b) fcu=60Mpa

Figure 6: Effect of Temperature on the Deflection

CONCLUSIONS

Based on the analysis of the experimental results of the tested RC beams containing discrete fibers exposed to

fires, the following conclusions can be drawn

- Adding fibers to concrete has a limited positive effect on the ultimate strength of the specimens compared to the control specimens. Its effect on the deflection due to fire is more pronounced.
- For NSC and HSC, in the case of fire and cooling by air, the strength capacity of tested beam was increased by increasing the fiber ratio. Also adding discrete steel fibers restrained the deflection. The reason may be due to bonding between steel fibers with the surrounding concrete which will act as confinement to the concrete and increased the tensile strength.
- For HSC, in the case of fire and cooling by water, the ductility was increased by increasing the fiber content from 0.0% to 0.50%, and decreased by increasing fiber ratio to 0.75% where the paste became less ductile.
- Exposing RC beams with HSC to fire then cooled by water jet, the cracks concentrated at middle zone of beams and decreasing cracks number with increasing in crack width, compared to NSC. The reason may be due to the cement past is strong as gravel and the Cracks usually appeared in the final stage of loading.
- In the case of fire and cooling by water the change of ductility and maximum deflection not proportional with discrete steel fiber content percentages.
- For NSC, in the case of fire and cooling by air, adding steel fiber content about 0.5% treatment any risky in capacity of load and deflection of RC tested beam. But in the case of fire and cooling by water adding steel fiber content about 0.5%, the elastic-plastic zone is decreased and the fracture zone increased due to working steel fiber as bridge after damage.
- For HSC, in the case of fire and cooling by water, the behavior of specimen similar to control beam. And the specimen more ductile than beam cooled by air. The reason may be due to cooling by water loss of part of deflection due to fire.

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